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LINEAR-DYNAMIC PROGRAMMING AS A BASIS FOR SETTING THE DIRECTIONS OF DEVELOPMENT FOR FIELD FARMS AGAINST CHANGES IN THE COMMON AGRICULTURAL POLICY IN MEDIUM-TERM PERSPECTIVE

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ABSTRACT

The purpose of the article is an attempt to determine, in the 2019 perspective, the economic situation of farms specialising in cereals, oilseeds and protein crops, with the economic size of 4–25 (very small), 25–50 (medium-small), 50–100 (medium-large) and 100 thousand EUR and more (large), operating on lower soils with the soil classification index (SCI) of up to 0.7, with an emphasis on changes in the Common Agricultural Policy (CAP) 2014–2020 as compared with the CAP 2007–2013. This was made using a model-based method (linear-dynamic programming method). These models adopted the maximisation of agricultural farm income as a criterion for optimisation. It was determined that the growth in income of these farms will be limited in case unfavourable pricing conditions on the market of biotechnological products and production measures last until 2019. This will mean that, in 2019, very small cereal farms will have no funds to pay the cost of farmer and his family's labour at the parity level and the cost of development, while medium-small cereal farms will have no funds for development. Only medium-large and large cereal farms will retain the possibility to pay the cost of farmer and his family's labour at the parity level and the cost of further development.

Key words: field farms, farm models, linear-dynamic programming, Common Agricultural Policy

INTRODUCTION

Along with introducing the principles of market economy after 1989, and especially after Poland's integration with the European Union (UE), the processes of specialisation and production concentration in agriculture intensified. The share of farms specialising in specified directions of production and the area of farms increased. This was caused by "differentiating" forces working throughout the last several decades on the market and inducing farms to specialise and concentrate their production[1]. An example is a significant share of farms

[1] According to T. Brinkmann, agriculture is influenced by two types of forces: "differentiating" and "integrating". Differentiating forces exist in the environment of farms, mainly on the market, and induce to specialise and concentrate production, while "integrating" forces are working within farms and encourages multilateral production, emphasising a more complete use of production factors as a result of using internal relations and dependencies [Brinkmann 1935].

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specialising in field cultivations[2]. In 2010 and 2013 the share of these farms in the overall number of farms amounted in Poland to 52% and 53%, respectively. These farms in Poland used adequately 31.4% and 45.5% of agricultural area. Type of farms specialised in field cultivations comprises two subtypes: farms specialising in cultivation of cereals, oilseeds and protein crops (type A), hereinafter referred to as cereal farms, and farmed specialising in cultivation of various plants [type B][3]. Poland is dominated by type A, the share of which in the number of plant farms amounted in 2013 to 93.5%, while type B farms comprised the remaining 6.5% [GUS 2015].

Taking into account an increasingly important role cereal farms play in the Polish agriculture, it is interesting how these farms will cope in worse natural conditions in the 2019 perspective. This is an important issue since the average soil classification ratio in Poland is 0.8 [GUS 2012]. Nearly 44% of agricultural area is located in agricultural farms situated on weak or very weak soils. In such an unfavourable situation, farmers who want to gain satisfactory income from agricultural production in a long-term perspective should represent, above all, high production culture compliant with requirements of the natural environment. But is this even possible when production means for agriculture become more expensive and changes in prices on the market of agricultural products are unexpected and often unfavourable? In this situation the next question arises – whether and how one can compensate the negative effects of further deterioration of price conditions in cereal farms taking into account changes in the CAP 2014–2020 as compared with the CAP 2007–2013.

The purpose of the study is thus an attempt to determine, in the 2019 perspective, the economic situation of cereal farms with the economic size of 4–25 (very small), 25–50 (medium-small), 50–100 (medium-large) and 100 thousand EUR and more of standard output (SO) (large) located on weaker soils with the soil classification index (SCI) of up to 0,7 and covered by the Polish FADN system in 2014[4]. This was made using a model-based method (linear-dynamic programming method[5]). These models adopted the maximisation of agricultural farm income as a criterion for optimisation.

MATERIAL AND METHODS

Linear programming (LP) is a field of mathematical programming, in which the dependence between expenditures and effects, as well as limiting conditions and objective function are linear. It is used to solve decision-making problems, abiding principles of rational management assuming obtaining a maximum of effects with given resources and expenses, or minimisation of outlays at the assumed result [Lange 1964, Weinschenck 1967, Rychlik 1974, Urban 1978, Ziętara 1981, Mańko 1987].

Methodical bases of the linear programming were developed by L. Kantorowicz before World War II. They were published in 1939, in a book entitled *Mathematical methods of organising and planning of production*. Polish edition was published in 1960 [Kantorowicz 1960]. It found its practical application in the period of World War II in arranging marine convoys with military equipment across the Northern Atlantic from the USA to the Soviet Union. These convoys were attacked by German submarines. The point was to determine optimum

[2] According to the typology of farms in accordance with the FADN methodology.

[3] These types of farms are marked with different symbols in the FADN typology. In order to simplify the analysis "A" and "B" names were adopted.

[4] The Polish FADN distinguishes six economic sizes of agricultural farms. In this article, however, the number of analysed groups was reduced by combining groups of farms with the least (up to 8 thousand EUR of SO and 8–25 thousand EUR of SO) and the greatest economic volume (100–500 thousand EUR of SO and more than 500 thousand EUR of SO). A premise for this approach was a small size of the group with the economic size of up to 8 thousand EUR of SO and a size of the group with more than 500 thousand EUR of SO in the Polish FADN database, not sufficient for the analysis.

[5] A five-year integrated linear-dynamic model was used.

proportions between freight and battle ships, with the objective function of minimising losses. After the war, linear programming was adopted in business activities, for the first time in the USA [Marszałkowicz 1986] and then in Europe, including Poland, to develop various kinds of plans in companies of economic sectors. In practice, there are different kinds of plans, depending on the adopted criteria of division, such as: time, nature, attitude to time horizon, subjective, material and areas [Manteuffel 1967, Ackoff 1973].

A basic criterion adopted in most cases is a time criterion, according to which the following plans are distinguished: daily (daily instruction), weekly, monthly, quarterly, campaign, annual, mid-term and long-term. Plans, from daily to annual inclusively, are often defined as short-term plans. Their subject is planning and implementation of work processes and production processes, acquisition and turnover of production, incurring outlays and implementation of tasks resulting from long-term plans. In industrial companies, apart from the annual plan, the greatest role is played by monthly and quarterly plans. On the other hand, in agricultural companies daily, weekly and campaign plans are of much importance. A mid-term planning horizon comprises the period of 2–5 years [Ziętara 1989].

Another criterion is the nature of plans. Tactical, operational and strategic plans are distinguished according to this criterion. It is connected with the previous one, differences relate to the content of plans. An annual plan is an operational plan.

An important criterion is also attitude to time. According to this criterion, there are static plans (one permanent planning period) and dynamic (rolling) plans including more planning periods (years).

A static approach was used, first of all, when preparing preliminary designs of economic instruments, which were mid-term plans insofar as their nature is concerned. On the other hand, a dynamic approach was used when developing annual plans. The linear-dynamic programming method was used for developing this kind of plans.

Other types of plans, distinguished according to the material, subjective and area criterion play no significant role from the point of view of the applied planning methods.

Linear programming, regardless of variable practical application, is used in scientific research, in particular with regard to testing anticipated results of specified solutions in the regulatory sphere. In a centrally planned economy, such as Poland until 1989, attempts were made at the turn of 1960/1970 to determine the optimum structure of sowings on the national scale using the linear programming [Leopold and Wdowiak 1968]. These results had cognitive values. In the Federal Republic of Germany linear programming is used in science in a broader perspective. In the 1970s a linear model was developed for the entire agriculture, which was used to study potential consequences of planned solutions in the regulatory sphere, e.g. reactions of farms of different scale to the planned support for agriculture in the form of preferential credits. The results obtained constituted the bases for making decisions under the agrarian policy [Bauersachs and Henrichsmeyer 1979]. Currently, this method is also used to define the effects of planned projects, both in the macro and micro scale. An example may be a publication entitled *Hydrothermal carbonisation profitability taking into account costs of transport* [Eberhardt and Odenig 2011]. The authors, using linear programming (GAMS model) described the profitability of carbonisation of straw, wood and energy willow for three carbonisation plants of various sizes and various costs of transport of raw materials and finished products to the power plant (depending on the distance). They demonstrated that this type of investments would be unprofitable without state's aid in the form of higher prices for CO_2 certificates. Another most current example is an article by E. Berg in which he presented relations with the natural condition in the context of mathematical programming [Berg 2012]. In the optimization model of agricultural farm he considered the risk related to changes in the condition of natural environment expressed by the level of precipitation, and ways to limit it by introducing sprinkling machines. He compared the proposed approach with a traditional one. A special attention should be paid to the proposed methodical approach.

In the Polish literature the linear programming method was used to the broadest extent in scientific research by E. Majewski and his team [Majewski et al. 1999, 2005, 2009].

Five-year integrated linear-dynamic models were used in this analysis[6]. The basis for construction of models were cereal farms located on weaker soils with the classification index of up to 0.7, covered by the Polish FADN system in 2014. For this year farm models were developed based upon actual data (resources, production structure, costs, revenues and performance) in order to verify their functioning. A very high degree of conformity (difference in farm income was lower than 8%). The next step was to optimise the production structure at prices and costs recorded in 2014 in conditions of the CAP 2007–2013. Performance of farms in 2014 was a basic solution for determining development directions of cereal farms in the period 2015–2019.

In the studied period, account was taken of changing prices of production means purchased by farmers and selling prices of agricultural products according to long-term trends (1995–2015). Changes in soil resources by means of lease and purchase were also accepted. It was assumed that purchase of land is possible in the case the farm has its own and external funds for development. Own funds constitute a surplus of agricultural farm income over the costs of own labour determined according to net labour rates in the national economy. In turn, external measures are short and long-term credits. Simultaneously, a limitation was introduced in the form of the need to maintain non-negative organic matter balance in the soil. Coefficients of soil reproduction and degradation of organic matter were adopted in a study entitled *Crop rotation in ecological agriculture* [Jończyk 2005]. A ratio of main harvest to harvest of plants straw collected by combine harvester was adopted in accordance with a suggestion of Harasim [2006]. On the other hand, the maximum share in the structure of sowings of particular plant species was established on the basis of methodology proposed by Kuś [1995]. The possibility of selling surpluses of straw was also accepted by Ziętara and Zieliński [2012][7].

The analysis took into account changes in the CAP 2014–2020 in relation to the CAP 2007–2013. In the period 2015–2019 direct payments covered a uniform area payment, payment under agricultural practices favourable for the climate and the environment (a so-called greening payment) and an additional payment. One also included a payment for less favoured areas management (LFA payment). In this case, pursuant to determinations of the Ministry of Agriculture and Rural Development (MRiRW), it was assumed that this payment will subject to new degressivity thresholds at the level of farm [MRiRW 2015].

RESULTS

The analysis demonstrated changes in the amount of resources of land used agriculturally in cereal farms in the target year (2019) as compared with the starting year (2014) and their scope depended on the economic size of farms.

In the studied period the condition of resources of land used agriculturally in very small cereal farms will increase by way of lease and purchase from 22.3 to 25.8 ha, i.e. by 15.7%. Within the structure of plant production

[6] The authors were, however, aware of its constraints, emphasising in a methodical chapter the meaning and possibilities for the use of linear-dynamic modeling. Therefore, in order to reduce their impact on the results of the analysis a relatively short projection period was used, while decision variables and limiting conditions contained in the matrix were determined based on the most recent, reliable data of the Central Statistical Office of Poland, Institute of Soil Science and Plant Cultivation – National Research Institution in Puławy and the Institute of Agricultural and Food Economics – National Research Institution. Moreover, developed models were each time subjected to the expert analysis based on a probable direction of changes in the agriculture sector in 2019.

[7] When preparing this analysis, the authors were trying to take advantage of the theory of economics, in particular the theory of environmental economics. It is because environmental economics addresses two main issues covering borderline areas related to economics and protection of natural environment. The first of them focuses on use and protection of natural resources. The second issue is associated with discussions of the methods of correcting human activities adversely affecting the environment, commonly referred to as external effects.

the share of winter wheat from 5.4 to 33.0%, winter rapeseed from 4.9 to 25.0%, and lupine and corn for grains, accordingly from 4.5 to 8.1% and from 2.2 to 25.0%. In turn, the share of winter triticale cultivation will decrease from 16.6 to 8.9% (Fig. 1)[8]. Labour resources determined on the basis of Polish FADN system for 2014 will amount in 2019 to 1.3 FWU[9]. In the period 2014–2019 in very small cereal farms, in spite of an increase in the area of arable lands and changes in the structure of plant production, agricultural income will remain almost unchanged (Table). This income will amount in 2019 to 18,286,6 PLN and is by 0.1% higher than in 2014 (18,262.7 PLN). An important cause of this situation will be unfavourable pricing conditions on the market of agricultural products and production measures lasting until 2019. In the examined period, the value of production will increase by 50.9%, whereas direct costs will be by 108.7% larger. Indirect costs will increase by 15.7%, and direct subsidies by 13.2%. Therefore, income of these farms in the target year will not be sufficient to pay the

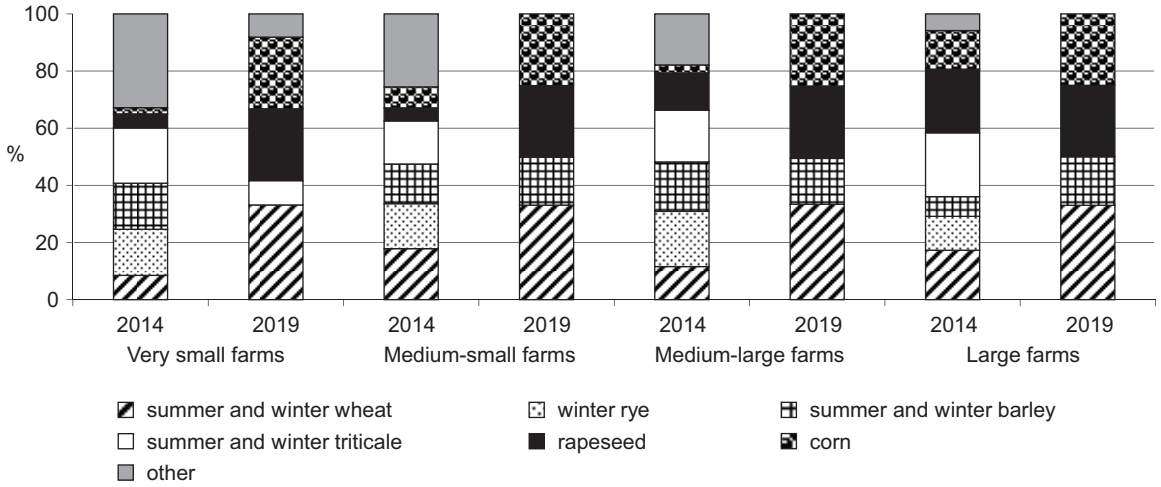

Fig. 1. The structure of plant production in cereal farms depending on the economic size in 2014 and 2019

Source: own study on the basis of Polish FADN system and linear-dynamic programming.

Table 1. Agricultural farm income from cereal farms depending on the economic size in 2014 and 2019

Specification	Type of farm							
	very small		medium-small		medium-large		large	
	2014	2019	2014	2019	2014	2019	2014	2019
Agricultural farm income (PLN)	18 262.7	18 286.6	62 811.5	64 112.3	132 928.3	137 487.6	277 854.1	338 440.3

Source: Own study on the basis of Polish FADN system and linear-dynamic programming.

[8] Agricultural farms holding accounts for the Polish FADN and located on weak soils within the structure of plant production have species of arable crops with higher soil requirements (spring and winter wheat and winter rapeseed). In these farms an important cause of this situation is high production culture, consistent with requirements of the natural environment. Straw ploughing, use of green fertilisers and natural fertilizers coming from the purchase provide for an increase in soil fertility.

[9] Family work unit (1 FWU = 2,120 h of work during the year) [Polish FADN 2014].

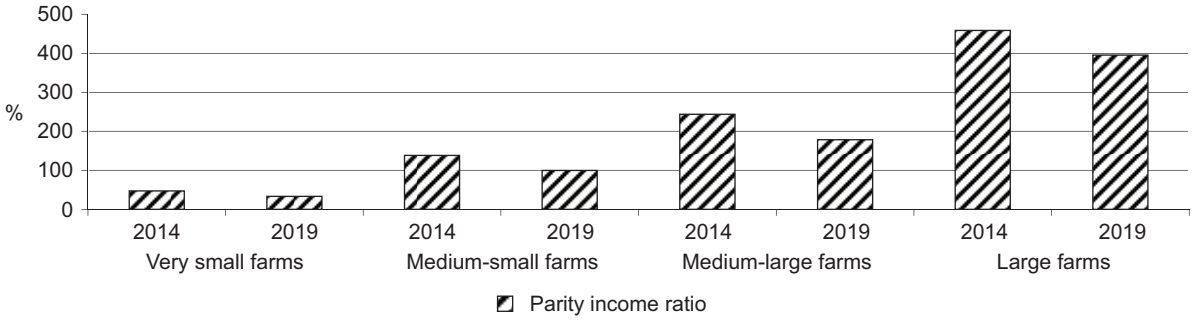

Fig. 2. Relation of agricultural farm income per one family work unit (FWU) to average salary in the national economy in the analysed cereal farms depending on the economic size in 2014 and 2019

Source: Own study on the basis of the Polish FADN and linear-dynamic programming.

costs of farmer and his family's labour at the parity level[10] and[11] (Fig. 2). Thus, these farms will not have funds for development as well, which will result in depreciation of their assets.

In the studied period the resources of land used agriculturally in medium-small cereal farms will increase from 50.4 to 64.1 ha, i.e. by 27.2%. In turn, plant production will be optimised by an increase in the share of wheat from 13.1 to 33.0%, winter barley from 1.0 to 8.9%, winter rapeseed from 4.6 to 25.0% and corn from 7.3 to 25.0% and by decrease in the share of spring barley from 12.9 to 8.1% (Fig. 1). Own labour inputs of farmer and his family will amount in 2019 to 1.5 FWU.

In 2019 agricultural income in medium-small cereal farm will amount to 64,112.3 PLN and will be 2.1% larger than in 2014 (Table). The value of production, direct and indirect costs will also increase, accordingly by 68.8, 123.5 and 27.2%. In turn, the value of granted direct subsidies will drop by 3.0%. In this farm an important cause of decrease in the value of granted direct subsidies will be their EUR/PLN exchange rate adopted in 2019[12], lower than in 2014, and the system of new degressivity thresholds of LFA payments determined in the CAP 2014–2020 unfavourable for farms larger in terms of area as compared with the CAP 2007–2013. Despite the above, considering the fact that unfavourable pricing conditions will last until 2019, income of this farm does not endanger the consumption of farmer and his family at the parity level, but will be insufficient for further increase in the value of fixed assets (Fig. 2).

In 2014 agricultural activities in medium-large cereal farms were carried out on 91.3 ha of arable land (AL), on the other hand, in 2019 it will be carried out on 131.9 ha of AL. Within the structure of plant production the share of wheat, rapeseed and corn will increase to the level of environmental constraints proposed by Kuś [1995] – Figure 1. In turn, own labour inputs of farmer and his family will amount in 2019 to 1.8 FWU. In 2019 income

[10]It was determined on the basis of parity revenue ratio, being a relation of agricultural farm income per one family work unit (FWU) to average salary in the national economy. The average salary in the national economy in 2019 was determined in the analysis on the basis of trends of changes in remuneration from the years 1995–2015. The rate of parity payment in 2019 was adopted at the level of 20.19 PLN per 1 h of work.

[11]In the analyses the category of agricultural income per 1 FWU was compared with the average salary in the national economy. Aware of differences in the scopes of both categories, the authors recognised as reasonably practical to introduce this type of comparison for cognitive purposes. It should be remembered that the comparison of both categories, in spite of its defects, is, next to the income from management, an important premise for informing on the justified character of agricultural activities in the agricultural farm. It is because it informs on the capacity to pay the cost of work of farmer and his family at the parity level and having measures for further development.

[12]It was assumed that in 2019 the EUR/PLN exchange rate will be an average from the years 2010–2014.

of medium-large cereal farms will increase by 4 559.3 PLN, namely by 3.4% as compared with the amount of income from 2014 (Table 1). The value of production will increase by 74.3%, direct costs by 129.3%, indirect costs by 44.5% and subsidies by 3.8%. However, the analysis demonstrated, that, even if unfavourable pricing conditions will last until 2019, income achieved by medium-large cereal farms will be sufficient to pay the costs of farmer and his family's labour at the parity level and the costs of further development (Fig. 2). On the other hand, larger differences in implemented income will occur in large cereal farms. In 2019 income of these farms will amount to 338,440.3 PLN and will be larger than in 2014 by 60,586.2 PLN, i.e. by 21.8% (Table). An important, but not sole cause of this positive state of affairs in these farms will be increase in the area of arable land from 211.3 ha in 2014 to 300 ha in 2019. It will be positively influenced also by optimisation of the structure of plant production, which will provide for increase in the share of plants of higher yield and, as a result, higher direct surpluses, such as wheat, rapeseed and corn, to the level of environmental limitations. As a consequence, with large area of the most profitable activities in plant production, possibilities for improving economic situation may be expected in these farms. In 2019 income of these farms will be sufficient to pay the costs of farmer and his family's labour at the parity level and the costs of further development (Fig. 2).

CONCLUSIONS

The subject of analysis was an attempt to estimate the effects of prolongation of unfavourable pricing conditions on the market of agricultural products and means of production to 2019 in relation to the amount of agricultural income realised in cereal farms located on weaker soils (WBG up to 0.7) taking into account changes in the CAP 2014–2020 as compared with the CAP 2007–2013. A point of reference was the situation of average cereal farms with the economic volume of 4–25 (very small farms), 25–50 (medium-small), 50–100 (medium-large) and 100 thousand EUR and more of SO (large) located on weaker soils and holding accounts for the needs of the Polish FADN in 2014.

On the basis of the conducted surveys, it can be concluded that in the examined period:

- In very small cereal farms, the effect of prolongation of negative trends typical of economic management conditions until 2019 will only be a small increase in their income. What's important, this growth will be positively influenced by an increase in the area of arable lands and an increase in direct subsidies granted. In 2019, however, they will not have an income large enough to pay the costs of living of farmer and his family at the parity level and the costs of development. Perspectives of their further continuation will thus be endangered.
- In medium-small and medium-large cereal farms the duration of unfavourable pricing conditions on the market of agricultural products and means for production until 2019 will limit an increase in their income. In medium-small cereal farms this income will remain however, at the level not posing a threat to the consumption of farmer and his family at the parity level, but will be insufficient for their further development. A better situation in this respect will be that of medium-large farms which will obtain in 2019 an income which will still be sufficient to pay the costs of work of farmer and his family at the parity level and the costs of further development.
- Income of large cereal farms will increase to the greatest extent. A positive cause of this situation will not only be a significant growth in the area of arable land, but also the optimisation of plant production structure, which will provide for an increase in the share of plants with higher direct surpluses, such as wheat, rapeseed and corn to the level of environmental constraints. These farms, in spite of the pricing recession on the market of agricultural products and means for production lasting until 2019, will thus be able to pay the costs of farmer and his family's labour at the parity level and increase the value of fixed assets they own.

A positive verification of suitability of models encourages to extend the scope of analysis of these issues by other production types of farms. Examples of use of farm models by E. Majewski and his team strengthen this belief.

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PROGRAMOWANIE LINIOWO-DYNAMICZNE JAKO PODSTAWA OKREŚLENIA KIERUNKÓW ROZWOJU GOSPODARSTW ROŚLINNYCH WOBEC ZMIAN WSPÓLNEJ POLITYKI ROLNEJ W PERSPEKTYWIE ŚREDNIOTERMINOWEJ

STRESZCZENIE

Celem artykułu jest próba ustalenia w perspektywie 2019 roku sytuacji ekonomicznej gospodarstw specjalizujących się w uprawie zbóż, roślin oleistych i białkowych o wielkości ekonomicznej 4–25 (bardzo małe), 25–50 (średnio małe), 50–100 (średnio duże) oraz 100 tysięcy EUR i więcej SO (duże) i funkcjonujących na glebach słabszych o wskaźniku bonitacji gleb (WBG) do 0,7 z uwzględnieniem zmian we wspólnej polityce rolnej (WPR) na lata 2014–2020 względem WPR na lata 2007–2013. W tym celu wykorzystano metodę modelową (metoda programowania liniowo-dynamicznego). W modelach tych jako kryterium optymalizacji przyjęto maksymalizację dochodu z gospodarstwa rolnego. Ustalono, że trwanie do 2019 roku niekorzystnych warunków cenowych na rynku produktów rolniczych i środków do produkcji ograniczy wzrost dochodu w tych gospodarstwach. W 2019 roku w gospodarstwach zbożowych bardzo małych oznaczać to będzie brak środków na opłacenie pracy rolnika i jego rodziny na poziomie parytetowym oraz na rozwój, a w gospodarstwach zbożowych średnio małych brak środków na rozwój. Tylko gospodarstwa zbożowe średnio duże i duże zachowają możliwość opłacenia pracy rolnika i jego rodziny na poziomie parytetowym oraz dalszego rozwoju.

Słowa kluczowe: gospodarstwa roślinne, modele gospodarstw, programowanie liniowo-dynamiczne, wspólna polityka rolna